

## **LOW TEMPERATURE METHODS OF BONDING COMPONENTS AND RELATED STRUCTURES**

### **RELATED APPLICATIONS**

The present application claims the benefit of priority from U.S. Application No. 10/017,350 filed December 14, 2001, which claims the benefit of priority from U.S. Provisional Application No. 60/256,072 entitled "Room  
5 Temperature Bonding Methods For Prepositioned Components And/Or Fibers" filed December 15, 2001. The disclosures of U.S. Utility Application No. 10/017,350 and Provisional Application No. 60/256,072 are hereby incorporated herein in their entirety by reference.

### **BACKGROUND OF THE INVENTION**

The present invention relates to methods of bonding components and more particularly to low temperature methods of bonding components and related structures.

It is known to bond components such as microelectronic devices to a  
15 substrate using solder reflow as discussed, for example, by E. Yung et al. in "Flip-Chip Process Utilizing Electroplated Solder Joints" (Proceedings of the Technical Conference, 1990 International Electronics Packaging Conference, September 10-12, 1990, pp. 1065-1079). Flip-chip technology (also known as C4 technology) relies on gang bonding of bumped pads to a substrate with a  
20 matching footprint. SnPb solder of high lead content can be used as the bump material. The bonding mechanism is the wetting of pad metallurgy during thermal reflow of solders. The disclosure of the Yung et al. reference is hereby incorporated herein in its entirety by reference.

Reflowing solder, however, means that the solder is heated above its  
25 melting temperature, and one or both of the substrate and/or the component may also be heated above the melting temperature of the solder. In some applications, excessive heating of the substrate and/or component may not be desired. In addition, the reflow of solder may result in the outgassing or evolution of materials such as flux which may leave an undesirable residue on  
30 the component and/or substrate.

## **SUMMARY OF THE INVENTION**

Methods of bonding components according to embodiments of the present invention may include positioning the components relative to one  
5 another to obtain a desired orientation, and bonding the components in the desired orientation with metal wherein a temperature of both components is maintained below a melting temperature of the metal while bonding. Damage to either component as a result of heating above a melting temperature may thus be reduced. In addition, outgassing and/or evolution of materials during  
10 bonding may be reduced. Moreover, misalignment resulting from thermal expansion under temperature can be reduced.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 is a cross-sectional view of a component bonded to a  
15 substrate using a metal layer according to embodiments of the present invention.

Figures 2A-B are cross-sectional views of intermediate steps of bonding a component and substrate using a metal layer according to embodiments of the present invention.

20 Figures 3A-D are perspective and cross-sectional views of an apparatus for bonding a component and a substrate according to embodiments of the present invention.

Figures 4-6 are cross-sectional views illustrating a component bonded to a substrate using metal particles according to embodiments of the present  
25 invention.

## **DETAILED DESCRIPTION**

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of  
30 the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the thickness and/or dimensions of

layers and regions are exaggerated for clarity. Like numbers refer to like elements throughout. It will be understood that when an element such as a layer, region or substrate is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present.

5 In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present. Also, when an element is referred to as being "bonded" to another element, it can be directly bonded to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly bonded" to another element, there  
10 are no intervening elements present.

According to embodiments of the present invention, two components can be bonded using a metal bond. More particularly, the two components can be positioned relative to one another to obtain a desired orientation, and the two components can be bonded in the desired orientation with the metal  
15 wherein a temperature of the components is maintained below a melting temperature of the metal while bonding. By way of example, the bonding metal can be plated on the components being bonded, or particles of the bonding metal can be provided on the two components and then bonded to each other and to the two components being bonded. While particular  
20 examples of bonding are discussed in greater detail below with respect to bonding an optical fiber to a substrate, metal bonding methods, structures, and apparatus according to the present invention can be applied to bonding substrates; optical components such as optical fibers, laser diodes, PIN diodes, vertical cavity surface emitting lasers, lenses, and/or gratings; micro-  
25 electronic components; and micro-mechanical components.

Figure 1 illustrates an optical fiber **31** that is bonded to a substrate **33** using a layer **35** of a plated metal. As shown, the fiber **31** includes a core **37** and cladding **39**. The optical fiber **31** can also include a metallized surface **41**, and the substrate can include a metallized surface **43** to facilitate plating  
30 thereon. The optical fiber **31** with the metallized surface **41** can thus be positioned relative to the substrate **33** to obtain a desired orientation therebetween, and the optical fiber can be bonded to the substrate in the desired orientation by plating the metal layer **35** thereon while maintaining the optical fiber **31** in the desired orientation relative to the substrate. By plating

the metal to bond the optical fiber to the substrate, bonding can be effected without significantly increasing the temperature of the substrate or optical fiber.

More particularly, the metal layer **35** can be plated using electroplating, electroless plating, electrophoretic plating, and/or any other plating techniques known to those having skill in the art. Moreover, the plating solution can be applied using selective plating of the substrate **33** and fiber **31** in a tank of the plating solution; using localized plating such as with a brush, a sponge, a pad, an open cell foam; and/or using any other application techniques known to those having skill in the art.

When using electroplating, a plating solution including the plating metal is applied to the metallized surfaces of the substrate and optical fiber, and an anode is provided in contact with the plating solution opposite the substrate. By applying an electrical potential between the anode and the metallized surfaces of the substrate and optical fiber, plating metal from the solution can be deposited on the metallized surfaces of the substrate and optical fiber.

When using electrophoretic plating, the plating solution includes dielectric particles in addition to the plating metal. Like electroplating, the plating solution is applied to the metallized surfaces of the substrate and the optical fiber, and an anode is provided in contact with the plating solution opposite the substrate. As with electroplating, plating metal from the solution can be deposited on the metallized surfaces of the substrate and the optical fiber by applying an electrical potential between the anode and the metallized surfaces. In electrophoretic plating, the dielectric particles in the plating solution can also be incorporated in the metal layer **35** to increase a deposition thickness and/or deposition rate of the metal layer. In other words, a desired thickness of the layer **35** can be obtained more quickly because of the dielectric particles incorporated therein. In addition, the use of glasses and/or oxides as the dielectric particles can decrease a creep rate and/or increase a stiffness of the plated metal layer.

When using electroless plating, there is no need for an anode or the application of an electrical potential. In this case, the surface **43** of the substrate and the surface **41** of the optical fiber are provided with a catalyst. As many metals may act as a catalyst for electroless plating, the surfaces of

the substrate and optical fiber can be metallized as discussed above. Alternatively, any other suitable electroless plating catalyst can be used in place of or in addition to metallization. By providing an electroless plating solution on the substrate and fiber with the appropriate catalyst thereon, the metal layer 35 can be plated thereon.

The metal layer 35 of Figure 1, for example, may have a relatively uniform thickness by applying the plating solution in a tank. Other techniques of applying the plating solution, however, may result in different cross-sectional profiles of the metal layer. Figures 2A-B illustrate the application of plating solution to the substrate 33' and the optical fiber 31' using an open cell foam plating pad 45 and a resulting metal layer 35' having a fillet shaped profile. By pressing the open cell plating pad 45 against the optical fiber and the substrate surface as shown in Figure 2A, the cells 36' on top of the optical fiber may be compressed thereby reducing mass transport of the plating solution to the top of the optical fiber. The plated metal layer 35' of Figure 2B can thus have a fillet shape which may be desirable for some applications. The open cell foam plating pad 45 of Figure 2A can thus be used to locally apply the plating solution.

Embodiments of an apparatus 49 for locally applying plating solution to an optical fiber and substrate are illustrated in perspective and cross-sectional views of Figures 3A-B. As shown, a plating solution 53 can be confined within a dielectric tube 51 (such as a quartz tube) having an open cell foam pad 55 at one end thereof. The apparatus can also include a flexible O-ring 57 to facilitate a better fit with optical fiber 59 and substrate 61. In addition, the apparatus can include an anode 63 for electroplating and/or electrophoretic plating. An anode may not be required, however, for plating operations that do not require an application of an electrical potential such as electroless plating. As shown, the apparatus can also include a mounting ring 65 used to manipulate and position the tube 51.

More particularly, the open cell foam pad 55 and dielectric tube 51 can confine the plating solution 53 so that the plating solution does not spread across the substrate 61. The open cell foam pad, however, can allow passage of the plating solution to the optical fiber 59 and portions of the substrate with which it is in contact. The apparatus of Figures 3A-B can thus

be used with electroplating solutions, electrophoretic plating solutions, and/or electroless plating solutions. With electroplating and/or electrophoretic plating solutions, an electrical potential can be applied between the anode and metallized surfaces of the substrate and optical fiber. With electroless plating solutions, the anode may not be required.

The optical fiber **59** can thus be positioned relative to the substrate **61** to obtain a desired orientation therebetween, and the optical fiber can be held in the desired orientation while the apparatus **49** is brought into contact with the optical fiber **59** and substrate **61**. More particularly, an actuator can be coupled to the mounting ring **65**, and the actuator can be used to position the apparatus on the optical fiber **59**. The flexible O-ring **57** can provide a seal with respect to the optical fiber and the substrate to reduce undesired spreading of plating solution across the substrate **61** surface. While the O-ring is illustrated in Figures 3A-B, the O-ring is not required. The tube **51**, for example, may include notches therein to allow passage of the fiber therethrough, and/or open cell foam may extend below the opening of the tube.

Alternatively, or in addition, a well may be provided in the substrate and/or a dam may be provided on the substrate to reduce undesired spreading of the plating solution. As shown in Figure 3C, dam(s) **66** on substrate **61'** may be used to reduce undesired spreading of the plating solution **53** across the surface of the substrate **61'**. As shown in Figure 3D, a well **68** (also referred to as a trench) in the substrate **61''** may be used to reduce undesired spreading of the plating solution **53** across the surface of the substrate **61''**. The apparatus **49** illustrated in Figures 3C and 3D can be the same as that illustrated in Figure 3B.

Moreover, the dam(s) **66** of Figure 3C can be provided by forming a patterned layer on the substrate, and the well **68** of Figure 3D can be provided by etching the substrate.

Once the apparatus **49** is brought into contact with the optical fiber and substrate, plating can begin. More particularly, plating solution **53** can feed through the open cell foam pad **55** to the optical fiber and the substrate **61**. While an open cell foam pad is discussed by way of example, other porous materials could be used in place of open cell foam. With electroplating and/or

electrophoretic plating, an electrical potential can be applied between the anode 63 and metallized surfaces of the substrate 61 and the optical fiber 59 to effect plating. With electroless plating, the anode may not be required.

Once a desired thickness of metal has been plated, the apparatus 49  
5 can be removed from the optical fiber and substrate, and the plated metal layer can bond the optical fiber to the substrate in the desired orientation. More particularly, a plated metal layer such as that illustrated in Figure 2B can bond the fiber and substrate. Because the optical fiber is now bonded with the plated metal layer, the fiber and/or substrate can be released from any  
10 equipment used for positioning during plating operations. The plated metal can be any metal suitable for plating such as, for example, nickel, lead, tin, silver, gold, and/or alloys thereof. The optical fiber can thus be bonded to a substrate using a metal layer while maintaining temperatures of the optical fiber and substrate below a melting temperature of the metal.

15 According to additional embodiments of the present invention, components can be bonded by providing particles of a metal adjacent the components and bonding the metal particles. As shown in Figure 4, a plurality of metal particles 71 can be provided adjacent the optical fiber 73 and the substrate 75, and the metal particles 71 can be bonded while  
20 temperatures of the optical fiber 73 and the substrate 75 are maintained below a melting temperature of the metal of the metal particles. The metal particles 71 may be in the form of a metal powder, for example, or the metal particles may include a dielectric material (such as a glass sphere) coated with metal. In addition, bonding surfaces of the substrate and optical fiber  
25 may be metallized and/or provided with a catalyst to facilitate bonding with the metal particles.

The metal particles can be provided adjacent to the optical fiber and substrate prior to positioning the optical fiber, and then bonded after positioning the optical fiber. Alternatively, the optical fiber can be positioned  
30 relative to the substrate, and then the metal particles can be provided adjacent the optical fiber and substrate and bonded. While the optical fiber and metal particles are shown on a relatively flat substrate in Figure 4, a well can be provided in the substrate, or a dam can be provided on the substrate to reduce spreading of the metal particles. In addition, the metal particles can

be provided on the optical fiber opposite the substrate and/or between the fiber and the substrate.

As shown in Figure 5, the substrate **75'** can have dam(s) **76** thereon to reduce spreading of the metal particles **71'** across the surface of the substrate surface prior to bonding the metal particles **71'** and the optical fiber **73'** to the substrate **75'**. As shown in Figure 6, the substrate **75''** can have a well **78** therein to reduce spreading of the metal particles **71''** across the surface of the substrate surface prior to bonding the metal particles **71''** and the optical fiber **73''** to the substrate **75''**. The bonding of particles **71'** and **71''** of Figures 5 and 6 is the same as that described with respect to the bonding of particles **71** of Figure 4. Moreover, the dam(s) **76** of figure 5 can be provided by forming a patterned layer on the substrate, and the well **78** of Figure 6 can be provided by etching the substrate.

The metal particles **71** can be bonded using plating techniques similar to those discussed above with respect to Figures 1, 2A-B, and 3A-B. In particular, an electroplating, electrophoretic plating, and/or an electroless plating solution can be applied to the metal particles **71** and an electrical potential applied thereto (if needed) to bond the metal particles to each other and to surfaces of the optical fiber **73** and to the substrate **75**. An apparatus similar to that of Figures 3A-B can be used to provide the plating solution and electrical potential (if needed).

According to alternative embodiments of the present invention, the metal particles **71** may be bonded by allowing diffusion between the metal particles. More particularly, the metal particles may comprise a metal having a relatively high diffusion rate at relatively low or ambient temperatures, such as indium. Accordingly, mere placement of the metal particles adjacent the substrate and optical fiber can result in bonding therebetween as the interfaces between metal particles **71** bond as a result of diffusion while maintaining the metal particles, optical fiber, and substrate below a melting temperature of the metal particles.

When using diffusion to bond the metal particles, it may be desirable to provide a diffusion barrier on the metal particles to reduce bonding during storage and to reduce bonding until the optical fiber has been positioned. A dielectric coating (such as an oxide), for example, may be provided on the



metal particles to reduce diffusion until diffusion and bonding are desired. Accordingly, the metal particles can be stored and applied to the substrate without bonding, and then bonding can be effected by rupturing the dielectric coating. The dielectric coatings of the metal particles can be ruptured, for example, by applying an electrical potential thereto. Exposed portions of the metal in the metal particles can then bond as a result of diffusion.

A diffusion barrier may also be provided on the metal particles by providing a first metal with a first diffusion rate and by providing a coating of a second metal with a second diffusion rate on the first metal wherein the second diffusion rate is lower than the first diffusion rate. Accordingly, bonding of particles can be reduced until the coating of the second metal is diffused into the first metal. For example, the first metal may comprise indium, and the second metal may comprise copper. Accordingly, copper coated indium particles can be stored at a low temperature to maintain the copper diffusion barrier, and when applied at room temperature, the copper coating will diffuse into the indium particle so that indium from different particles can diffuse across interfaces therebetween to provide bonding. Alternatively, titanium, chromium, nickel, iridium, copper, and/or alloys thereof can be used to provide diffusion barriers on indium particles. A metal diffusion barrier can be provided on indium particles, for example, by vacuum deposition, chemical vapor deposition, or displacement reaction.

In addition, a diffusion barrier may be provided by a coating of a solid material that sublimates at room temperature. For example, indium particles can be coated with naphthalene or carbon dioxide and stored at a temperature sufficient to maintain the diffusion barrier in the solid state. Once the indium particles have been dispensed at room temperature, the diffusion barrier will sublime thereby allowing diffusion and bonding between indium particles.

Diffusion between metal particles can also be inhibited by vibrating the metal particles until bonding is desired. The metal particles, for example, can be maintained in a vibrating dispenser, and vibration (such as ultrasonic vibration) can be used to inhibit bonding of the metal particles. Once the metal particles are dispensed on a stationary substrate and optical fiber, diffusion and bonding can occur. Alternatively, the metal particles can be

dispensed on the optical fiber and substrate which are vibrated until a desired orientation is achieved, and the vibration is ceased to allow diffusion and bonding.

Alternatively, diffusion between metal particles can be inhibited by  
5 providing the metal particles in a foam such as a cellulose foam. As long as the foam is maintained, many of the particles will be separated. Accordingly, the metal particles can be stored and dispensed as a foam, and the foam can be applied to the optical fiber and substrate without initiating bonding. Once the desired position of the optical fiber is achieved, diffusion and bonding can  
10 be initiated by collapsing the foam so that the metal particles come into contact and diffusion and bonding occur. The foam can be collapsed, for example, by adding a detergent and/or by introducing an atmosphere (such as nitrogen) that increases a surface tension of the foam.

By using metal particles having a high diffusion rate, bonding can be  
15 achieved at room temperature without generating excessive residues that might degrade a light path. Accordingly, post bonding cleaning may be reduced. In addition, bonding can be achieved relatively quickly. The use of diffusion to bond metal particles can also be referred to as cold welding. Moreover, the speed of diffusion and thus bonding can be increased by  
20 providing a flow of electrons through the metal particles, and/or by increasing a temperature of the metal particles to a temperature less than a melting temperature of the metal particles. By providing a flow of electrons through the metal particles, movements of metal atoms can be accelerated as a result of pressure due to electron flux, also referred to as electromigration. Cold  
25 welding can also be accelerated by applying pressure to the metal particles.

The metal particles can also be bonded by applying sufficient current through the metal particles so that metal particles are welded at interfaces therebetween. Here the increased welding temperature may be localized to interfaces between metal particles where current densities are the highest  
30 without significantly heating the bulk of the metal particles so that temperatures of the optical fiber and/or the substrate are maintained below the melting temperature of the metal. Bonding interfaces of metal particles using an electrical current to effect a weld may be done quickly without significantly increasing temperatures of the substrate and optical fiber.

Moreover, the metal particles to be welded can comprise metal(s) having a relatively low creep rate and having relatively high stiffness so that a relatively rigid bond can be provided. Moreover, a metal bond may be effected without generating significant residues and/or particles. The bonding current, for example, could be generated using an arc discharge from a capacitor.

The metal particles used for bonding can alternatively comprise a metal that amalgamates with a liquid species at a temperature less than the melting temperature of the metal. The metal particles, for example, can be silver and/or gallium particles that amalgamate with mercury to generate an alloy thereof and to bond the particles. Accordingly, metal particles can be provided on the optical fiber and substrate either before or after positioning, and once the desired position is achieved, the liquid species can be introduced to the metal particles to effect alloying and bonding. The liquid species can be applied, for example, through a brush, a sponge, a pad, an open cell foam, or using any other application techniques known to those having skill in the art. Moreover, an apparatus similar to that illustrated in Figures 3A-B could be used to apply the liquid species.

According to additional embodiments of the present invention, corrosion may be used to bond metal particles. By facilitating corrosion of a mass of metal particles, interfaces of adjacent metal particles may bond as the respective layers of corrosion on different particles grow and merge. The corrosion, for example, can be the result of oxidation or galvanic corrosion.

As an example of bonding using oxidation, the metal particles may comprise iron. Once a desired position of the optical fiber has been achieved, iron particles adjacent the optical fiber and substrate can be exposed to moisture to facilitate oxidation of the iron particles. The oxide (rust) of adjacent iron particles can grow such that the respective rust layers merge to bond the adjacent particles. Bonding using oxidation can thus be effected without generating significant residues and without significantly increasing temperatures of the substrate or optical fiber.

Alternatively, galvanic corrosion can be used to effect bonding of adjacent particles. For example, the metal particles can include a mixture of particles of dissimilar metals such as aluminum and steel or aluminum and zinc. Galvanic corrosion and bonding of the particles can be initiated by

introducing moisture to the particles so that substitution of the dissimilar metals (otherwise referred to as galvanic corrosion) results in bonding of the metal particles. Prior to bonding, bonding can be inhibited by maintaining the particles of dissimilar metals separate and/or dry.

5           Alternatively, bonding can be provided by a displacement reaction implemented using particles of a first metal and then applying a solution of a second more noble metal. For example, a solution of zinc can be applied to aluminum particles to cause galvanic corrosion of the aluminum particles. Since aluminum is trivalent and zinc is divalent, there is an increase in particle  
10 volume, further increasing an intimacy of contact between the particles, component, and substrate. In other words, zinc atoms will be substituted for aluminum atoms at the surface of the aluminum particles, and because three zinc atoms will be substituted for every two aluminum atoms replaced, the aluminum particles will grow as a result of the galvanic corrosion (also  
15 referred to as a substitution reaction). Accordingly, the aluminum particles can bond at interfaces therebetween as zinc is substituted for aluminum. Moreover, the solution of the dissimilar metal can be applied through a brush, a sponge, a pad, an open cell foam, or using any other application techniques known to those having skill in the art. Displacement reactions can thus be  
20 used to bond metal particles without significantly increasing temperatures of the optical fiber or substrate and without generating significant residues. Surfaces of the component and/or substrate may also be metallized with aluminum to further facilitate bonding.

          The various techniques discussed above can thus be used to provide  
25 metal bonding between two components while maintaining the two components below a melting temperature of the bonding metal. While bonding of an optical fiber to a substrate is discussed by way of example, methods, structures, and apparatus according to embodiments of the present invention can be applied to the bonding of substrates, optical components,  
30 micro-electronic components, and/or micro-mechanical components. Moreover, the particular metals and/or solutions discussed for providing bonding are discussed by way of example only without limiting the present invention to the particular examples discussed.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the  
5 following claims.